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Preliminary Results of Stability Study for the KTeV Beam

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version 2.2

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ABSTRACT

KTeV requires ≤±100 μm beam position stability (horizontal and vertical)[1]. The new SEEDs were designed to have resolution such that this stability is measurable. The program AUTOTUNE was developed to maintain this stability. By looking at data we see that the stability required is both achievable and maintainable.

I. Introduction

SWIC (and SEED) data were collected using the EPICURE data logging utility[2]; data from 21 November 1996 to 12 December 1996 was used. This data was then reformatted into ntuples and analyzed using PAW. 11401 data were used—4404 before AUTOTUNE[3] was implemented and 6997 afterwards.

Each SWIC or SEED may be set to sample data from one to ten times during each spill. In this case, the SEED was set for ten scans; scan five was used to calculate pulse-to-pulse stability because it is used in AUTOTUNE. Stability during the spill was calculated by taking the difference between scan ten and scan three (scans one and two were dropped because of effects caused by pings).

The position of the beam, $\bar{x}$, was calculated by:

$$\bar{x} = \frac{\sum_{n=1}^{48} n w_n}{\sum_{n=1}^{48} w_n} \qquad \text{Eq. 1}$$

where n is the SWIC wire and w_n is the signal on the wire. Although the SEED in question, NM2SEED2, is quite noisy, no attempt was made to eliminate the noise; however, the effects of the noise were estimated.

AUTOTUNE performs a double-pass calculation. First, $\bar{x}_1$ is calculated as above. Next, $\bar{x}_2$ is calculated using the wires $[\bar{x}_1 - m + 0.5, \bar{x}_1 + m + 0.5]$, i.e., $\pm m$ wires of the average. The

1 KTeV Beam Systems Design Report, version 1.0. Table 2.1.1

2 written by Bob West

3 G. Gutierrez, Autotune Proposal for KTeV (included as appendix)
J. DeVoy, AutoTune, RD Controls Software Release Note 157

difference between $\bar{x}_2$ and the ideal position, x^*, is the correction, δx. AUTOTUNE calculates δx for spill i and changes magnet currents so that if the beam does not change δx will equal zero at spill $i+1$.

In order to estimate the effects of noise on the calculated beam position, data with no beam were also used. A histogram of this noise was made for each wire, then the shape was fitted. Finally, a gaussian profile was generated, noise consistent with the histograms was added to each wire, the new shape integerized, and the mean caclulated as in Eq. 1.

II. Initial Stability Calculations

These results are based on the simple calculation of the beam position, not the more complicated double-pass method used in AUTOTUNE.

Figures 1a and 1b show the vertical and horizontal beam position for scan five as a function of time. The units for the abscissa are days; the units for the ordinate are wires. The vertical line at day six is when autotuning began. It is evident from the graphs that long-term stability has improved since AUTOTUNE was implemented. Two possible exceptions are during day 15, when there were problems with power supply regulation, and a short period on day 16.

Histograms 2a-2d show the vertical and horizontal averages, summed over the collected data, both before and after AUTOTUNE was implemented. In both, the RMS has decreased, and the distribution approaches a Gaussian shape. From these histograms the beam stability may be calculated by multiplying the RMS by the wire spacing.

Recalling that NM2SEED2 has a 125 μm wire spacing, we summarize the stability in table 1:

Table 1. Stability before and after implemetation of AUTOTUNE.

NM2SEED2	Before	After	Improvement
Vertical	71.9	54.8	17.1
Horizontal	83.4	56.5	26.9
All units are μm			

Finally, stability during the spill ("beam roll") may be examined. Figures 3a and 3b show the difference in the average vertical and horizontal positions for scans ten and three. The horizontal line in each graph is at zero. We see that horizontally the beam does not roll by more than about one wire (125 μm). Vertically, the roll was quite dramatic until day 13, when a faulty power supply was repaired. The "scatter" between days 14 and 16 are also due to regulation problems.

Histograms 4a-4b show the vertical and horizontal beam roll (top and bottom rows, respectively) before and after day 13 (left and right columns, respectively). The results are summarized in table 2 below:

Table 2. Beam roll before and after day 13.

NM2SEED2	Before	After
Vertical	115	12.7
Horizontal	9.19	11.3
All units are μm		

III. Effects of Noise

Several (12,255) scans without beam were analyzed. For each wire, a histogram of the noise was made. The distribution was approximated by:

$$y = e^{-0.60709n} \qquad \text{Eq. 2}$$

where n is the number of counts and y is the noise.

In order to estimate the effect of this noise on the calculation of the mean, the following procedure was used:

1. Generate a gaussian profile over wires 1 through 48, with mean $\bar{x}$ and sigma σ.
2. Add noise to profile, consistent with Eq. 2, using the CERN random number routine RNDM.
3. Integerize the profile (the SWIC scanner returns data as an integer between 1 and 127).
4. Calculate the mean, $\bar{x}^*$.
5. Take the difference $\delta x = \bar{x}^* - \bar{x}$.
6. Repeat steps 1-5 several (1,000) times, and calculate the mean and RMS for δx ($\overline{\delta x}$ and $\sigma_{\overline{\delta x}}$).

This procedure was repeated with $\bar{x}$ ranging from 22 to 27, in 0.1 wire increments, and σ ranging from 6 to 9, in 0.1 wire increments.

The results were that $\overline{\delta x}$ ranged from -0.45 wires to 0.45 wires as $\bar{x}$ ranged from 22 to 27 wires, and $\sigma_{\overline{\delta x}}$ ranged from 0.37 wires to 0.23 wires as σ ranged from 6 to 9 wires. Tables 3 a and b summarize some values.

Table 3a. Difference between actual mean and calculated mean as a function of actual mean and actual sigma.

Actual Mean	Actual Sigma			
	6.00	7.00	8.00	9.00
22.00	-0.45	-0.38	-0.25	-0.13
23.00	-0.26	-0.20	-0.15	-0.08
24.00	-0.08	-0.09	-0.05	-0.02
25.00	+0.08	+0.07	+0.05	+0.02
26.00	+0.26	+0.22	+0.14	+0.07
27.00	+0.44	+0.36	+0.25	+0.11
All units are wires.				

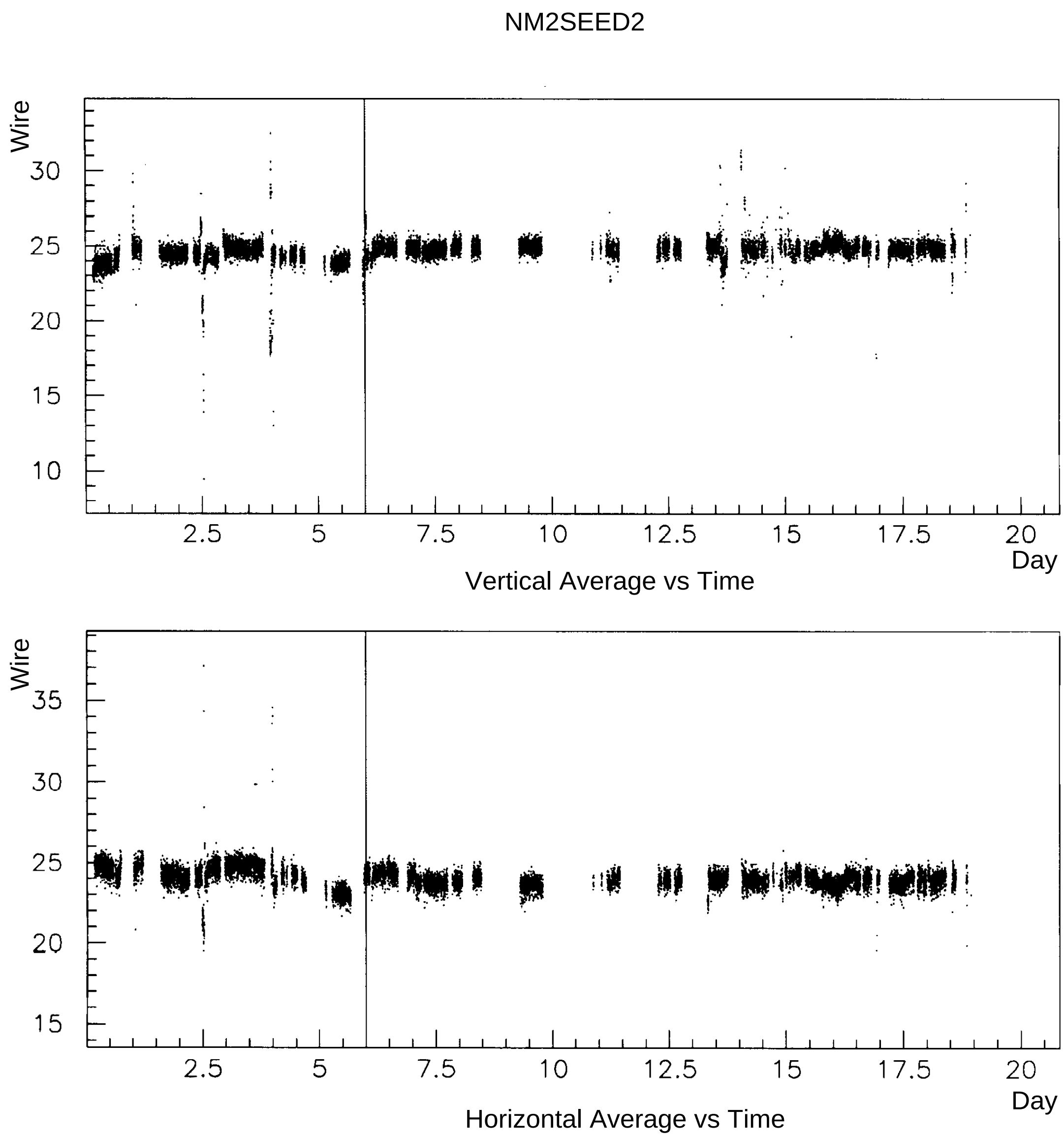
Table 3b. RMS of calculated mean as a function of actual mean and actual sigma.

Actual Mean	Actual Sigma			
	6.00	7.00	8.00	9.00
22.00	0.35	0.31	0.26	0.24
23.00	0.35	0.29	0.24	0.23
24.00	0.37	0.30	0.24	0.23
25.00	0.35	0.30	0.25	0.23
26.00	0.35	0.30	0.26	0.23
27.00	0.34	0.31	0.27	0.24
All units are wires				

The profile on NM2SEED2 has a vertical mean and RMS of 24.5 and 7.5 wires, and a horizontal mean and RMS of 24.5 and 7.4 wires. Looking up the values of $\overline{\delta x}$ and $\sigma_{\overline{\delta x}}$ in a table yield $\overline{\delta x}$ =0.0 wires and $\sigma_{\overline{\delta x}}$=0.28 wires in either plane, or 0 µm and 35 µm.

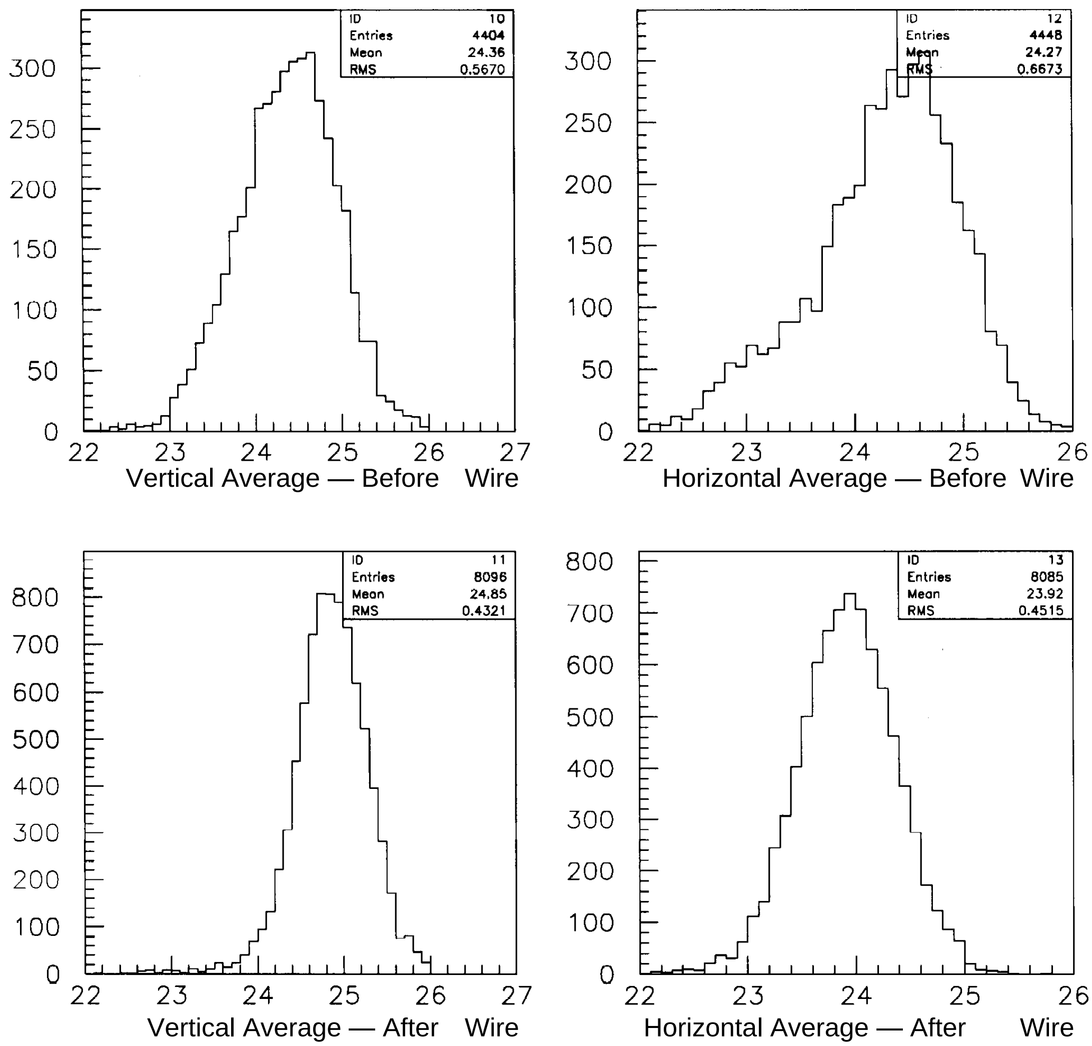
IV. Conclusion

The spill-to-spill stability of the beam is better than 60 µm. Implementing the AUTOTUNE program has improved this stability. Between scans three and ten the beam rolls across the target by about 12 µm; elimination of this source of error is not possible with AUTOTUNE.

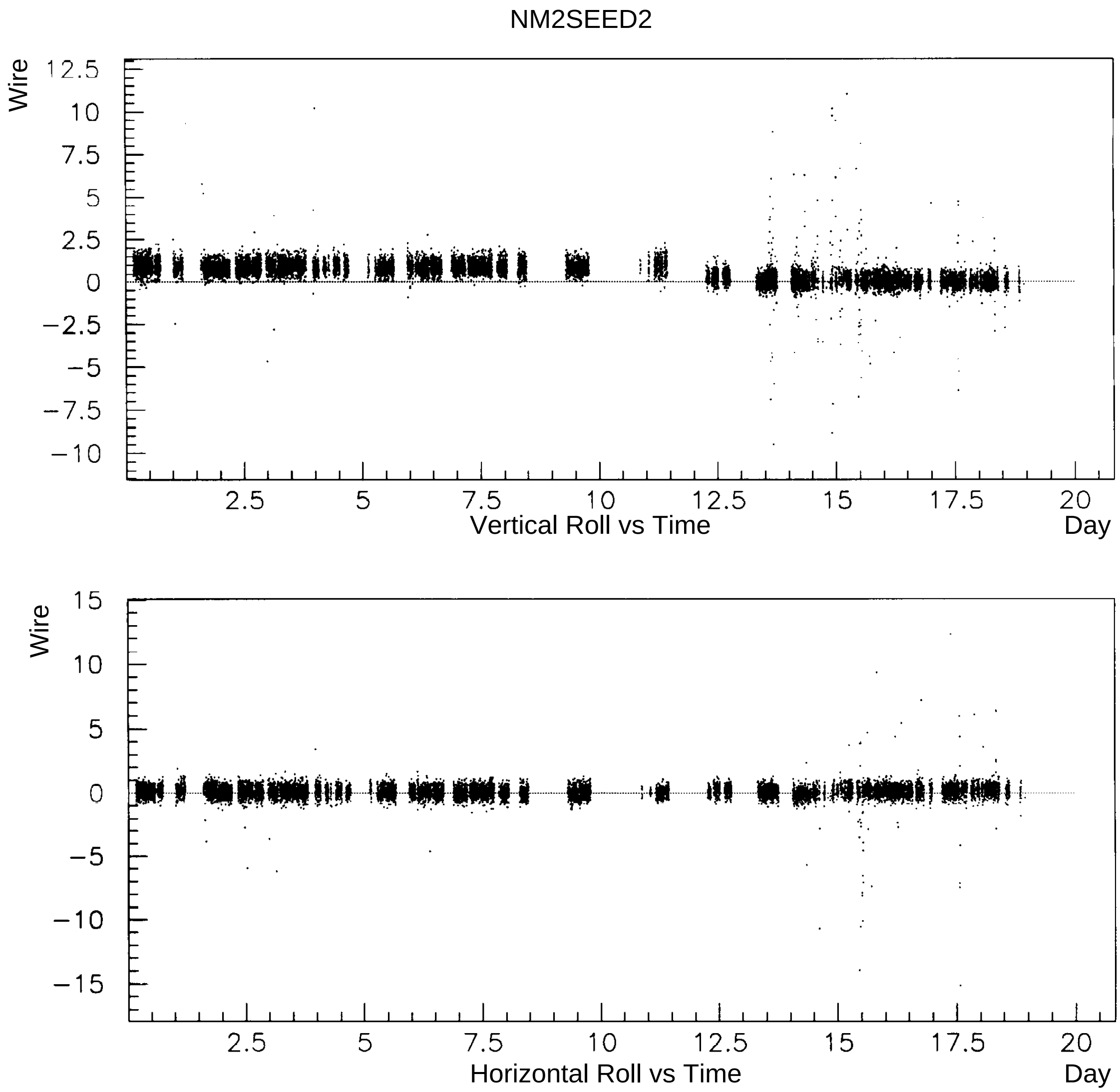


Figs. 1a and 1b

NM2SEED2

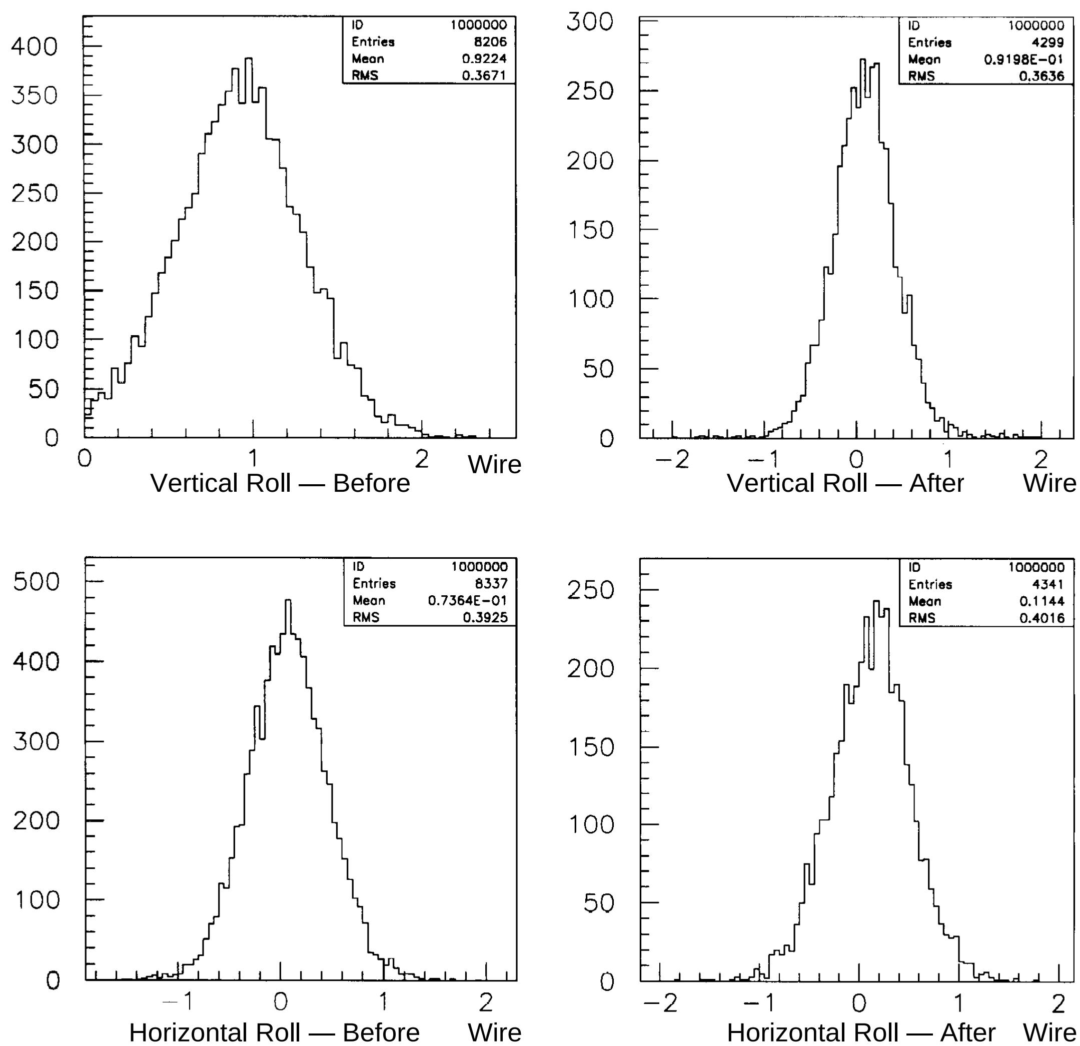


Figs. 2a - 2d



Figs. 3a and 3b

NM2SEED2



Figs. 4a - 4d

Appendix
Autotune proposal for KTeV

With the regular settings of NM2Q1 at 730.6 amps and NM2Q2 at -746 amps the relationship between changes in magnet's fields and beam positions is given by (the units are mm/KGauss):

		NM0H	NM0V	NM1U	NM1H	NM2EU	NM2V	NM2H	NM2D2
NM1WC	H	28.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NM1WC	V	0.00	8.96	0.00	0.00	0.00	0.00	0.00	0.00
NM2WC1	H	44.74	0.00	0.00	3.94	1.92	0.00	0.00	0.00
NM2WC1	V	0.00	14.49	32.40	0.00	1.19	0.03	0.00	0.00
NM2SEED1	H	2.50	0.00	0.00	1.55	20.79	0.00	0.22	0.00
NM2SEED1	V	0.00	5.58	15.41	0.00	4.11	0.59	0.00	0.79
NM2SEED2	H	-0.17	0.00	0.01	1.50	23.47	0.00	0.36	0.00
NM2SEED2	V	0.00	2.02	7.39	0.00	3.73	0.57	0.00	1.90

With the above table it is possible to study the accuracy that is needed in the beam position measurements to achieve a 50 μm and 20 μrad beam stability at the target.

Horizontal stability

The case in which the magnets NM0H and NM1H, and the SWICs NM1WC and NM2WC1 are used, will be studied first. A change in NM0H to produce a motion in NM1WC of Δx_{NM1WC} will move the beam at the SEEDs by the amount:

$$\Delta x_{NM2SEED1} = \frac{2.50}{28.15}\,\Delta x_{NM1WC} = \quad 0.089\,\Delta x_{NM1WC}$$

$$\Delta x_{NM2SEED2} = \frac{-0.17}{28.15}\,\Delta x_{NM1WC} = -0.006\,\Delta x_{NM1WC}$$

And for NM1H

$$\Delta x_{NM2SEED1} = \frac{1.55}{3.94}\,\Delta x_{NM2WC1} = 0.393\,\Delta x_{NM2WC1}$$

$$\Delta x_{NM2SEED2} = \frac{1.50}{3.94}\,\Delta x_{NM2WC1} = 0.0381\,\Delta x_{NM2WC1}$$

If the errors in the position measurement at NM1WC and NM2WC1 are uncorrelated, the total error in NM2SEED2 is given by

$$\sigma^{H}_{NM2SEED2} = \sqrt{(0.006\,\sigma^{H}_{NM1WC})^2 + (0.381\,\sigma^{H}_{NM2WC1})^2}$$

Therefore to achieve a stability of $\sigma^{H}_{NM2SEED2} = 50\,\mu\mathrm{m}$ the beam has to be measured at the upstream end of NM2 with a precision of $\sigma^{H}_{NM2WC1} = 130\,\mu\mathrm{m}$. AND RIGHT NOW THAT CAPABILITY IS NOT THERE !

Assuming that the distance between NM2SEED1 and NM2SEED2 is 5 meters (the distance in the TRANSPORT deck is 4.97 meters), the error in the slope is given by

$$\sigma_\theta^H = \sqrt{\left[\left(\frac{2.5+0.17}{28.15\times 5000}\times 10^6\right)\sigma_{NM1WC}^H\right]^2 + \left[\left(\frac{1.55-1.50}{3.94\times 5000}\times 10^6\right)\sigma_{NM2WC1}^H\right]^2}$$
$$= \sqrt{(19\,\sigma_{NM1WC}^H)^2 + (2.5\,\sigma_{NM2WC1}^H)^2} \quad \mu\text{radians}$$

Therefore a 1mm accuracy in the position measurements will be enough the achieve a $20\,\mu\text{rad}$ angular stability.

The above calculations show that NM2EU has to be included to control the beam position at the target. The minimum step in NM2EU is 0.183 amps, which reflects in a change of 12 μm at NM2SEED2, so the resolution in the current is there. The error in the slope introduced by using NM2EU will be:

$$\Delta\theta_H = \frac{\Delta x_{NM2SEED2} - \Delta x_{NM2SEED1}}{5000}\times 10^6$$
$$= \frac{1-0.886}{5000}\times 10^6\ \Delta x_{NM2SEED2} = 23\ \Delta x_{NM2SEED2}$$

So a change of 0.050 mm in NM2SEED2 produces a change of 1 μrad in the slope.

Therefore the best solution for the horizontal control is to use the magnets NM0H, NM1H, NM2EU, the SWICs NM1WC, NM2WC1, NM2SEED2, and to require an accuracy in the beam position of 1 mm, 1 mm and 0.050 mm respectively.

Vertical stability

The vertical stability can be calculated in the same way the horizontal stability was calculated above. If only NM0V and NM1U are used then the error in the position is:

$$\sigma_{NM2SEED2}^V = \sqrt{(0.225\,\sigma_{NM1WC}^V)^2 + (0.228\,\sigma_{NM2WC1}^V)^2}$$

Then for a stability of $\sigma_{NM2SEED2}^V = 50\ \mu\text{m}$ the beam position at NM1 and the upstream end of NM2 has to be measured with an accuracy of $\sigma_{NM1WC}^V \approx \sigma_{NM2WC1}^V \approx 160\ \mu\text{m}$, and that is not possible at the moment.

The error for the vertical slope is given by:

$$\sigma_\theta^V = \sqrt{(79\,\sigma_{NM1WC}^V)^2 + (49\,\sigma_{NM2WC1}^V)^2} \quad \mu\text{radians}$$

Therefore $\sigma_{NM1WC}^V \approx \sigma_{NM2WC1}^V \approx 1\text{ mm}$ will give a vertical angular stability of $\sigma_\theta^V \approx 90\ \mu\text{rad}$, which should be fine.

Again the above calculations show that to achieve a vertical stability of 50 μm, NM2V and NM2SEED2 will have to be used. NM2V has the capability of making changes at NM2SEED2 producing only small changes in the angle. The error in the angle coming from the use of NM2V is:

$$\Delta\theta_V = \frac{1-1.035}{5000} \times 10^6 \ \Delta y_{NM2SEED2} = -7 \ \Delta y_{NM2SEED2}$$

Which gives and error of 0.35 μrad when the beam is moved at NM2SEED2 by 50 μm.

Therefore the best solution for the vertical control is to use the magnets NM0V, NM1U, NM2V, the SWICs NM1WC, NM2WC1, NM2SEED2, and to required an accuracy in the beam position of 1 mm, 1 mm and 0.050 mm respectively.